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Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem

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Abstract: The role of automation in sustainable development is not in doubt. Computerization in particular has permeated every facet of human endeavour, enhancing the provision of information for decision-making that reduces cost of operation, promotes productivity and socioeconomic prosperity and cohesion. Hence, a new field called information and communication technology for development (ICT4D) has emerged. Nonetheless, the need to ensure environmentally friendly computing has led to this research study with particular focus on green computing in Africa. This is against the backdrop that the continent is feared to suffer most from the vulnerability of climate change and the impact of environmental risk. Using Nigeria as a test case, this paper gauges the green computing awareness level of Africans via sample survey. It also attempts to institutionalize green computing maturity model with a view to optimizing the level of citizens awareness amid inherent uncertainties like low bandwidth, poor network and erratic power in an emerging African market. Consequently, we classified the problem as a stochastic optimization problem and applied metaheuristic search algorithm to determine the best sensitization strategy. Although there are alternative ways of promoting green computing education, the metaheuristic search we conducted indicated that an online real-time solution that not only drives but preserves timely conversations on electronic waste (e-waste) management and energy saving techniques among the citizenry is cutting edge. The authors therefore reviewed literature, gathered requirements, modelled the proposed solution using Universal Modelling Language (UML) and developed a prototype. The proposed solution is a web-based multi-tier e-Green computing system that educates computer users on innovative techniques of managing computers and accessories in an environmentally friendly way. We found out that such a real-time web-based interactive forum does not only stimulate the interest of the common man in environment-related issues, but also raises awareness about the impact his computer-related activities have on mother earth. This way, he willingly becomes part of the solution to environment degradation in his circle of influence.

Keywords: green computing; economic security; environmental sustainability; information economy; sustainable development; Sub-Saharan Africa

1. Introduction

In recent times, there has been unprecedented growth in Africa's cyberspace leading to socioeconomic growth and sustainable development. This is particularly so as more original equipment manufacturing (OEM) companies are imbibing the philosophy of inclusive innovation, propelling them to develop relatively cheap technologies that fit the purchasing power of users in developing economies [1,2]. Hence, cheaper phones, computers, telecommunication equipment and other accessories purposely built for emerging markets are strengthening the vision of digital inclusion. However, associated with this development is the need to promote environmentally sustainable computing that limits the impact of global warming and environmental degradation [3]. This is particularly concerning in that projected figures of Africa's vulnerability to climate change and environment risk by global environmental assessing bodies like IPDA, the UN, and so forth, are quite alarming. Already, flash floods [4], gully erosion, coastal erosion, and desert encroachment are threatening livelihood, posing economic insecurity challenges, and in extreme cases, culminating in humanitarian crisis.

Green computing embraces green infrastructure [5] and refers to the efficient and effective handling of computers, servers and accessories such as printers, monitors, networking/communication gadgets, and storage devices with minimal or zero environmental impact by studying and adopting global best practice in their design, manufacture, usage, and disposal [6]. Preliminary investigation revealed that despite the expansion of the African computing community, there is low level of green computing awareness. The implication is that Africans continue to use information and communication technology (ICT) to support their livelihoods with little concern for the adverse impact of computing on the environment. Meanwhile, computing by both corporate and individual users have been known to scale up global warming through carbon emission, degrade the environment through release of hazardous chemicals, and deplete energy availability. Many computing businesses depends on fuel generators for power supply in the absence of regular electricity from national grids. The presence of carbon in each hydrocarbon fuel (petroleum, natural gas, and coal) entails that it is released as carbon dioxide (CO_2) during combustion [7]. Conversely, non-combustible sources such as sunlight, wind, nuclear, and hydropower [8] do not have the capacity to transform hydrocarbons to CO_2, which is widely acknowledged as a heat-trapping greenhouse gas [9,10]. As acknowledged by scientists, the release into the atmosphere of greenhouse gases (GHGs) adversely impacts on the climate system. Nonetheless, since cost-benefit analysis indicates that the benefits of ICT way outweighs its costs, measures have to be put in place for environmentally sustainable usage of ICT in Sub-Saharan Africa.

In this work, we proposed that one of such measures is stepping up green computing [5] awareness in Africa's cyberspace. Educating computer users will empower them with the right information to be innovative and creative about the use of ICT facilities vis-a-vis the environment [11]. An adequate green computing campaign can be launched in each African country in the fight against the adverse effect on climate change. Although a number of campaign initiatives are available, we concern ourselves basically with the solution option with maximum impact. Hence, we investigated an optimization problem. For the success of any green computing campaign nationally, support from government in terms of resources and enforcement systems are needed. It is therefore a source of concern that Africa's socioeconomic landscape is characterised by deficient legal system, poor regulatory framework, weak institutions, infrastructure deficit, and near non-existent standards [12], among others. The combined effect is a precarious climate that breeds corruption, mutual distrust and low productivity across all sectors, including the computing sector. This underscores the fact that the decision to optimize green computing awareness in a social-economic system with stochastic behaviour is a stochastic optimization problem [13].

Having classified the problem, we identified effective actions that could move the process from one state to another along the green computing awareness creation value chain as a knowledge gap analysis, the identification of suitable campaign initiative in socio-cultural context, the application of preferred initiative and, finally, an impact assessment of the initiative on computer users' behaviour.

We then mathematically modelled the African green computing awareness decision environment as sequential decision-making under uncertainty using stochastic finite automaton [14]. Subsequently, the authors applied metaheuristic algorithm [15,16] to the sequencing and selection process to ascertain the best-known awareness campaign initiative to be used. The outcome led to the use of a software engineering approach (component-based software engineering or CBSE) for the design and development of a web-based e-Green Computing system. The proposed n-tier solution is aimed at promoting environmentally sustainable computing education for positive behavioural change towards the environment [17].

The rest of the article is partitioned as follows: in Section 2, we provide the background of the study and related work; methodology and a selected case study are presented in Section 3; in Section 4, the results are discussed; and we conclude the paper in Section 5.

2. Background and Related Work

2.1. Electronic Waste

Electronic waste (e-waste) refers to electronic products that have attained the end of useful life and as such have become obsolete, unwanted, non-working and can be discarded. Nonetheless, they can be useful to some people or industry as raw material. Many electronic products have the propensity to become waste after some few years of usage on account of rapid technological advancement. For example, scenarios of e-waste generation include replacement of VCRs by DVD players, and also the replacement of DVD players by Blu-ray players. Anything electronic (TV, computer, monitors, cell phones, VCR, PDAs, fax machines, CD players, printers) creates waste.

2.2. Green Computing and Sustainable Development

Green computing refers to the efficient utilization of computers and accessories such that they contribute minimally to environmental degradation. These devices are known to contain harmful chemicals and emit gaseous emissions when in use and out of use. It also encompasses efficient energy utilization. Socioeconomic activities that contribute to national economic indicators such as real gross domestic product (GDP), income, employment, manufacturing and retails sales [18] have to take into cognisance an environment that is humanly friendly as captured by the global policy framework called sustainable development goals [19]. This means both the natural environment and social environment [20] have to be protected. Though computing contribute greatly to socioeconomic activities [21,22], it has been observed that e-waste from the use of information and communication technologies (ICTs) have to be properly articulated to guarantee a friendly ecosystem [1] for socioeconomic and sustainable development activities to thrive. Plastic and metallic e-wastes, for example, are known to be non-biodegradable and can harden the soil when disposed indiscriminately, resulting in flooding [4]. E-waste apart, the design, production and usage of ICTs should minimize the amount of energy consumed by ICT so that green computing [5] can contribute maximally to sustainable development. Apart from the hazardous greenhouse gases (GHGs) that emanate from e-waste during their disposal into the atmosphere [7], many business centres rely on generators in developing economies to power their businesses. Equally, highly automated corporate businesses do same to be able to survive in the less than impressive business environment in which they operate. As result, a lot of carbon fuel is burnt to sustain computer-driven businesses with implications for CO_2 emissions into the atmosphere. The advocacy for clean energy [21] in emerging economies is receiving little attention owing to poverty levels [2,23]. In any case, in the context of the reality on ground, green computing awareness has to be intensified across all strata of businesses to ensure the environment is not devastated [3] by ICT-related activities. For instance, corporate organizations through their corporate social responsibility (CSR) portfolio [24] could raise green computing awareness among computer users and merchants [25]. Such campaigns will purely target

acceptable environmental behaviours [17] that protect and preserve the natural and social environments for sustainable development.

2.3. Metaheuristic Algorithm for Optimal Green Computing Awareness

Our study assessed a number of potential initiatives for creating users awareness on green computing in the African context. The initiatives examined are:

- establishing functional regulatory bodies;
- use of traditional media awareness;
- use of web-based social media;
- organizing workshops and seminars;
- establishing waste collection and quantification systems; and
- organizing a road walk campaign.

An emerging market such as Africa is characterized uncertainties [26] predicated on constraints such as resource availability, literacy level, infrastructure deficit, epileptic power supply, and weak institutions, among others. Hence, our decision to create optimal green computing education in a geopolitical space with stochastic (probabilistic) behaviour exhibits trappings of stochastic finite automaton [14] as shown in Figure 1.

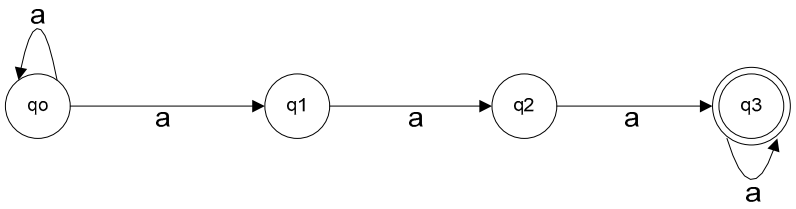

Figure 1. Stochastic finite automaton for green computing awareness creation process.

This is mathematically expressed as M* = (Q,A,q_0,∂, p, F) such that

Q = set of states that is finite
A = set of actions that is not empty
q_0 ϵ Q = start state
F Q = set of final states;
Q A Q = finite set of transition between states; where
p is a function ∂ [0,1] and all q ϵ Q; for all a ϵ A
$\sum p(q, a, q') = 1$.

For a finite state automaton to be stochastic, the transition rules have to be defined by transition probabilities while the initial and final states have to be defined by probability distributions [13]. In this instance, the inputs into the sequential decision making process of the green computing awareness campaign are:

a_0 = Knowledge gap analysis of computer end-users in Sub-Saharan Africa
a_1 = Identification of suitable campaign option for creating maximum awareness in the socio-cultural context of each African country
a_2 = Application of identified approach
a_3 = Evaluation of the impact of applied approach.

The function P (∂→[0,1]) entails that the occurrence of each outcome has a probability value assigned to it.

In any case, the research focus was to get the best way to execute the campaign, taking into cognizance each socio-cultural context. This means optimal decision has to be taken amid uncertainties that are hallmarks of developing economies in Africa. We therefore x-rayed each of the green computing awareness-creating initiatives, focusing on capacity to engineer environmentally sustainable computing behavioural change measured by power of attraction, speed of message delivery, and message retention.

Since the solution space is populated with viable alternatives, with each having potential for delivery, the quest for the best-known solution took centre stage. The researchers thus applied Tabu Search, a metaheuristic Algorithms 1 and 2, as follows:

Algorithm 1: Tabu Search

```
s ← s0
sBestInitiative ← s
awarenessTabuList ← null
 while (not awarenessSearchStoppingCondition())
    awarenessCandidateList ← null
    for(awarenessCandidate in searchNeighborhood)
         if(not containsTabuElements(awarenessCandidate,
         awarenessTabuList))
              awarenessCandidateList ← awarenessCandidateList
              + awarenessCandidate
         end
    end
    awarenessCandidate ←
    LocateBestAwarenessCandidate(awarenessCandidateList)
    s ← awarenessCandidate
    if(fitness(awarenessCandidate) > fitness(sBestAwareness))
       awarenessTabuList ←
       featureDifferences(awarenessCandidate,
       sBestAdmission)
       sBestAwareness ← awarenessCandidate
       while(size(awarenessTabuList) >
             maxAwarenessTabuListSize)
       ExpireFeatures(awarenessTabuList)
             s ← awarenessTabuLIstFirstElements
        end
   end
 end
 return(sBestAwareness)
```

Using parameters likes power of attraction, speed of message delivery and message retention capability, the metaheuristic search indicated that of all the aforementioned green computing enlightenment strategies, a web-based social media platform would best serve the purpose of maximum green computing awareness. Hence, the researchers relied on software design and development skills to actualize a multi-tier web-based e-Green computing system. Specifically, component-based software engineering (CBSE) approach was applied. +

Meanwhile, mathematically, the optimization problem is:

Algorithm 2: Green Computing Awareness Maximization Function

```
Max
            Green Computing awareness
Subject to
            Availability of funds
            Access to network infrastructure
            Literacy level
```

2.4. Related Work

Previous efforts that have bearing with the subject matter in the literature are presented as follows.

Saha [27] defined green computing as the act of sustaining computing performance while ensuring that computing resources are utilized in an environment friendly manner. After a literature survey of green computing, the author emphasized its significance to sustainable development. The study emphasized that an organization (United Nations Framework Convention on Climate Change or UNFCCC) has been working hard towards circumventing adverse anthropogenic (human-induced) climate change. Already, manufacturers of ICT accessories have been compelled to meet various energy standards owing to a combination of factors that includes consciousness of global warming and promulgation of environmental regulations and laws. The paper concluded that the present and future technological needs will not be compromised in that green computing will achieve a healthier, safer and greener environment via its structured, methodical and sustainable approach. Though the study highlighted efforts being made globally to promote environmentally tolerable behaviours, it did not state specifically state how to optimize green computing awareness in an emerging economy like Africa that is faced with uncertainties, which is the key motivation for our study.

Mittal and Kaur [28] conducted a survey to gauge the common man's understanding of issues related to green computing. A survey questionnaire incorporating major green computing was administered in the first instance as a pilot study before the actual survey. The paper opined that green computing is an effective approach aimed at energy efficient products. The authors are of the view that with the aid of green computing, we can achieve the dual objectives of saving energy and shielding the environment from adverse impacts of computers and its accessories. While decrying the low-level of awareness about the harmful impacts of the use of computer on environment, the study stressed that most of the CO_2 emission is produced through the heat generated by the computer and its devices. Another challenge posed to the environment by computing is energy consumption by various computing devices. Despite comprehensively highlighting factors related to green computing and measuring the common man's awareness level of the subject, the study stopped short of suggesting ways to scale up awareness level. Neither did it consider making and implementing such a decision under uncertainty like this African study presents.

Shinde et al. [29] is an expository study on green computing, also called green technology. The paper posited that it is the efficient and effective use of computers and accessories such as printers, monitors, networking/communication systems, and storage devices such that there is minimal or zero impact on the environment. The work stressed that green computing will optimize energy efficiency in the lifetime of a product, mitigate usage of hazardous materials, and ensure that factory waste and defunct products can be recycled and biodegradable. The study observed that the upsurge in the use of computers for domestic, official and business purposes has led to unprecedented increase in the quantity of electricity they consumed and scaled up atmospheric carbon content. Against this reality, measures are now being taken by people to minimize the power usage of computers as the reduction in the use of energy occasioned by green computing techniques will scale down carbon dioxide emissions. This arises from reduction in amount of fossil fuel utilized in transportation and power plants. Resource conservation entails less energy is needed for product development, usage and

disposal. In the same vein, prudence in the use of energy and resources saves money. The researchers are of the view that change in government policy to facilitate recycling, as well as scaling down energy usage by both businesses and individuals, are the two cardinal objectives of green computing. Though the authors mentioned that people have taken appropriate measures, they were not specific. In our study, we advocate a cohesive national programme for raising green computing awareness among numerous computer users.

Therese and Albert [13] worked on sequential decision-making in unpredictable circumstances and opined that stochastic finite automata can be used as a mathematical model for decision making under uncertainty. They emphasized that decisions such as launching a comprehensive green computing campaign in an emerging economy can be an uphill task that likely involves to some extent uncertainty. A decision environment refers to a set of information, values, preferences, and alternatives made available at the decision moment while a sequential decision problem encompasses sequential states that are likely interdependent or independent. Thus, in each state action has to be taken, and a sequence of actions is required to obtain a solution. A decision taken at a state based on an action is transferred to next subsequent state, and the entire decision chain is a function of all decisions taken at all the states. The study reiterated that complex systems exhibiting stochastic behaviour in a finite manner can be modelled mathematically using stochastic finite automata. The authors concluded that in the event transition rules are measured by transition probabilities then the finite state automaton is categorized as stochastic just as probability distributions are used to define final and initial states. Though the study did not specifically focus on the green computing awareness problem, it provided a framework for rightly classifying such an exercise in an emerging economy with trademark uncertainties and instabilities.

Silberholz and Golden [15] used solution quality and runtime as barometers for comparing metaheuristics. They opined that since metaheuristics are meant to overrun exact approaches in terms of giving quality solutions in runtimes that exact approaches cannot boast of, they can only be meaningful if acceptable solutions are given within reasonable time. A metric that represents solution quality is required as benchmark for comparing two algorithms in the context of solution quality, and comparison should be done over same problem instances as comparison over different instances are weaker since they have un-identical structures, difficulties and optimal values. Besides demonstrating good solution quality, another critical necessity is that they must have a fast runtime. Otherwise, we cannot justify the preference of metaheuristics over exact algorithms. The authors stressed that making runtime comparisons are difficult in nature. Challenges involved in comparing runtimes of algorithms compiled with different compilers and executed on heterogeneous computers, potentially on different testbeds, have aggravated the situation. Despite comparing and discussing how to secure greater value from optimization techniques, the work did not dwell on optimizing green computing awareness under uncertainty.

Glover [16] chronicled the creation of Tabu Search as a metaheuristic algorithm. It can be applied to stochastic optimization problems. These are problems that require optimal sequencing and selection of best-known solution under uncertainty. The author emphasized that local (neighbourhood) searches such as picking best-known green computing awareness creation strategy from a pool of strategies take a potential solution to a problem and investigate its proximate neighbours with a view to obtaining a better solution. There is the propensity for local search methods to become stuck where many similar solutions exist. In such suboptimal scenarios (or plateaus) of equally fit solutions, Tabu Search pushes the limits by using memory structures. The memory structures describe and harbour user-provided collection of rules and already visited solutions, thereby enhancing performance. The algorithm avoids considering a solution repeatedly by ensuring that if such solution has been hitherto visited within a particular short-term period or has contradicted a rule, it is logged as Tabu. This means forbidden. Among other application areas, the author confirmed that it is also used in resource planning—this is key to mobilizing human and material resources towards environmentally sustainable computing. Though the study outlined the modus operandi of Tabu Search and reiterated its potentials for tackling

resource planning problem, it was silent on the impact of green computing awareness on environmental sustainability and economic security.

3. Methodology—The e-Green Computing System

In identifying requirements for the e-Green Computing system and to get an insight into current trend in cyberspace, relevant literature was consulted, interviews held, questionnaire administered and the Nigerian cyberspace observed as a reasonable representation of Sub-Saharan Africa.

Green computing process and procedures were modelled using the Universal Modeling Language; specifically, we used use cases, collaboration diagrams, sequence diagrams, class diagram and deployment diagram.

The Microsoft SharePoint was then used as implementation platform for a prototype after designing and developing the proposed solution leveraging CBSE approach. The proof-of-technology was set up at the Centre for Information Technology and Systems (CITS), University of Lagos, Lagos, Nigeria, and tested from Abuja and Lagos, respectively. Microsoft SharePoint supports four major components namely: Document Library; Custom List, Task, and; Site. The tool was used because it supports the doctrine of component reusability with COM+ as its component model. It is also a web-based platform that supports distributed computing.

The researchers performed a number of controlled experiments using real-life and simulated data. The participants in the experiments had ample opportunity to interact with the system. Thereafter, they shared their insights on the potency of the proposed social media application to drive online real-time conversations between green computing stakeholders, achieve the goal of promoting environmental friendly computing education and ultimately stimulate appropriate end-user behaviour. The authors then evaluated possible threats to research outcome.

We used Nigeria as a case study amid established concerns that it has one of the largest ICT users' population on the African continent. Besides representing in microcosm the African continent in terms of demography, Nigeria accounts for 29% of internet usage on the continent, making it Africa's largest ICT market [30]. To actualize the proposed e-Green Computing system as a measure for promoting environment-friendly computing behaviours in the African cyberspace and computing community in general, CBSE lifecycle activities were used guided by the objective-methodology mapping shown in Table 1.

Table 1. Objective-Methodology Mapping.

SN	Objective	Methodology
1.	To drive online real-time conversation on environmentally friendly computing in the African cyberspace	Design and implement an e-Green Computing system
2.	To ascertain proposed system can bring about desired end-user behaviour	Verify and validate the e-Green Computing system

3.1. Requirements Analysis and Specification

In this section, we give a breakdown of the requirements for the e-Green Computing system. The requirements were gathered by interview, questionnaire and observation of the Nigerian cyberspace and computing community. The social functions required are access information, add information, delete information, and edit information (Table 2). The quality (non-functional) requirements are security, performance, aesthetics, usability, availability, scalability, reliability, modifiability, fault tolerance, interoperability and portability. The web-based n-tier e-Green Computing system has inbuilt mechanisms that meet these requirements.

Table 2. Functional Requirements.

Requirement ID	Requirement	Brief Description
R01	Add Information	The e-Green Computing system will allow computer users to add information on green computing techniques based on assigned rights and privileges
R02	Access Information	The e-Green Computing system will allow computer users to retrieve and view information on green computing practices within assigned rights and privileges
R03	Edit Information	The e-Green Computing system will allow computer users to edit information related to environmentally friendly computing in line with assigned rights and privileges
R04	Delete Information	The e-Green Computing system will allow users to delete information from the database based on allocated rights and privileges

Use case modelling was used (Figure 2) to consolidate requirements analysis in a bid to comprehend the core functionalities and usage scenarios associated with the proposed system's requirements. The researchers, in attempt to capture the functional aspects of the e-Green Computing system, used the use case diagram to graphically depict actors' interactions with the system [31].

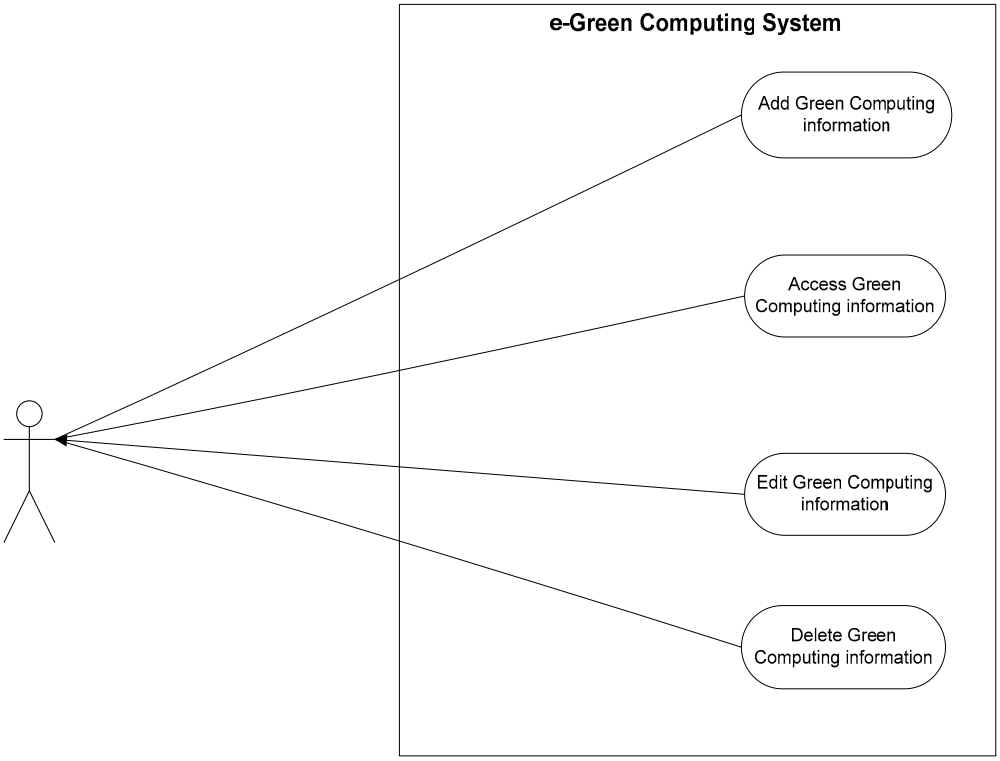

Figure 2. Use Cases for e-Green Computing System.

The use cases empower the computing community to articulate and share information on global best practices on e-waste management, carbon emission and computer-related energy efficiency schemes. The end goal is to promote environmentally acceptable computing habits and behaviours.

3.2. System and Software Design

Distributed computing and component reusability are closely linked in an enterprise application such as the e-Green Computing system. To leverage this relationship, a multi-tier enterprise architecture was designed for the proposed solution. It has inbuilt mechanisms that meet user requirements.

The n-tier architecture is made up of presentation layer, logic layer and database layer. While corporate and individual ICT users operate at the presentation layer as end-users using devices like personal computers and phones to contribute or access information on environmentally tolerable practices, the logic layer made of clustered application servers process the information which is stored in the database layer. The essence of networking these layers is to make dialogue online real-time.

The links between respective e-Green Computing components are shown in Figure 3. Though the COM+ component model is not visibly represented in the software architecture in line with best practices [32], its role in the architecture is critical as it offers support services to, and provides standards for the system components. The interdependence between Access Information, Add Information, Delete Information, and Edit Information as graphically shown underpins the reality that conversations on green computing initiated by one party can be supported or debunked by another, and it is expected that such healthy online social media debate will translate into enlightened computers users with responsibility for the environment. Hence, appropriate habits and behaviours towards the environment are cultivated. This way, the green computing awareness campaign would have made significant impact on the environment.

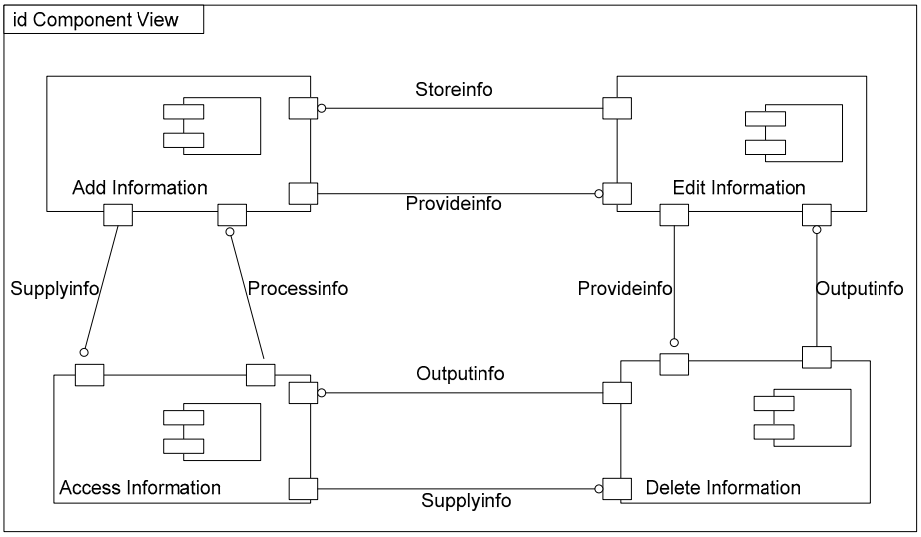

Figure 3. e-Green Computing component diagram.

The e-Green Computing reusable components (Access Information, Add Information, Delete Information and Edit Information) were subsequently built using Microsoft SharePoint standard components.

The class diagram for the e-Green Computing system is given in Figure 4 below.

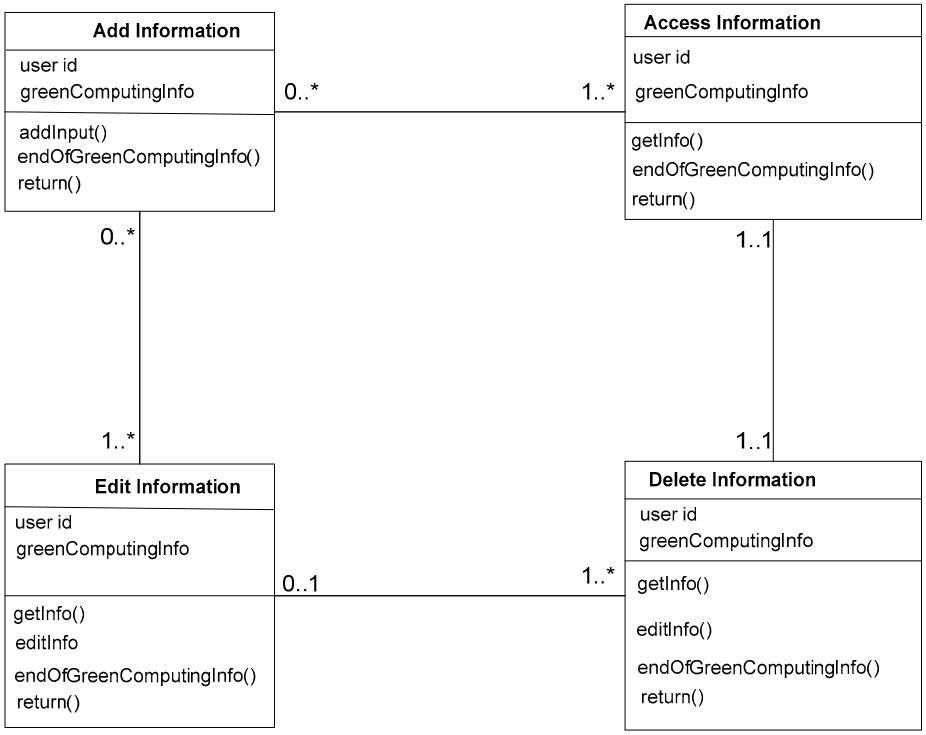

Figure 4. e-Green Computing class diagram.

Other design tools we used include a collaboration diagram, sequence diagrams, a class diagram, an analysis class, a design component and an elaborated design class, class elaboration, an algorithm, composite (appropriate) interfaces, and an elaborated deployment diagram [33,34].

The researchers used a deployment diagram to represent the location of key packages or components of the e-Green system [33]. The study equally used class elaboration and an algorithm to present abstraction details of the components and social functions of the proposed e-Green Computing system.

3.3. Implementation and Unit Testing

The study used as development tool Microsoft SharePoint for the tailor-made e-Green Computing system. The testbed was set up at the University of Lagos Centre for Information Technology and Systems (CITS), Lagos, Nigeria. As a web-based enterprise development tool, SharePoint makes components (also referred to as services) available for reuse. Besides providing an integrated development environment (IDE), it uses Microsoft COM+ as component model for enhancing interoperability among system components. Its traditional components are distributed as well as independent [32] and include Custom List, Document Library, and Tasks. We developed the e-Green Computing system on an incremental basis. The addInformation module was the minimal e-Green Computing system to commence with followed by the addition of other modules. Since black box testing is more suitable for component-based systems, the authors used it [35].

3.4. System Integration

With addInformation as minimal e-Green Computing system, we carried out regression test with the addition of subsequent modules with a view to ascertaining the presence of any interface errors. If in the event of adding a module an error emerged, debugging was done prior to adding another module. Ultimately, the addInformation function was the most tested component in the e-Green Computing system. It is the most referenced component in the proposed system. Prior to integrating the various components, each was tested using test cases. At the integration point, we used system test

cases for regression tests. As expected of component-based systems, black box testing was performed for all components [36]. Table 3 shows the function points.

Table 3. Component Testing—Function Points.

SN	Component	Function Points
1.	e-Green Computing	Add Green Computing Info, Access Green Computing Info, Edit Green Computing Info, Delete Green Computing Info

Hence, besides developing and implementing test case for each of the e-Green Computing reusable components (Access Information, Add Information, Delete Information and Edit Information), the system test case was administered at the point of integrating each to ensure the robust regression test revealed any existing error.

3.5. System Verification and Validation

The requirements-compliance and process-correctness of the proposed systems were verified and validated by an assessment of the respective software representations that include design documents, requirements documents, and program code. We focused on ensuring that in the build-up process, each software representation was well catered for. We likewise ensured that both emergent properties and user operational needs were met by the software product.

3.6. Operation Support and Maintenance

Role-based training was conducted for select technical personnel and end-users for the purpose of test-running the application. The technical staff were saddled with the responsibility of providing system support, whereas end-users operated the software.

4. Results and Discussion

The study extracted information and measured outcomes in two ways—software experiment and sample survey of computer users. We also evaluated possible threats to the research outcomes. Our evaluation mechanics are presented as follows:

4.1. Results of Software Experiment

The e-Green Computing site was created as a community site using Microsoft SharePoint enterprise development platform. As the name goes, it is a site where cyberspace members discuss topics that bother on environmentally friendly utilization of computers and accessories. The underlying message of this software engineering is that conscious and concerted efforts towards preventing computer-related environmental degradation can add mileage to ongoing global efforts to mitigate the adverse effect of climate change. This is to be achieved by leveraging online real-time discussion between cyberspace participants on new techniques of green computing. We set up an experimental design in University of Lagos, Nigeria, precisely at the Centre for Information Technology and Systems (CITS) and test-run the system from nearby (Lagos environs) and remote locations like Abuja, both in Nigeria. By this act, the researchers used a multi-tier web-based e-Green Computing system to mimic the sensation of sustained dialogue between African computing community members.

The simulation experiment affirmed that ICT could be instrumental to solving the problem e-waste and energy conservation management through sustained online real-time green computing conversations and education. The subjects who participated in the experiment concurred that the output of the experimental survey was a seamless and robust online real-time communication among cyberspace stakeholders on topical green computing services that geared toward the protection

and management of the environment. The endgame is that the e-Green Computing dialogue framework engendered a sense of users' awareness on the role green computing plays in environmental sustainability and economic security. Though we experienced platform- and hardware-dependent challenges particularly testing from remote location like and Abuja, this buttressed the fact that the problem is a stochastic optimization problem in which we attempted to maximize the gains of creating green computing awareness under uncertainty.

Figures 5 and 6 are snapshots from the experiment.

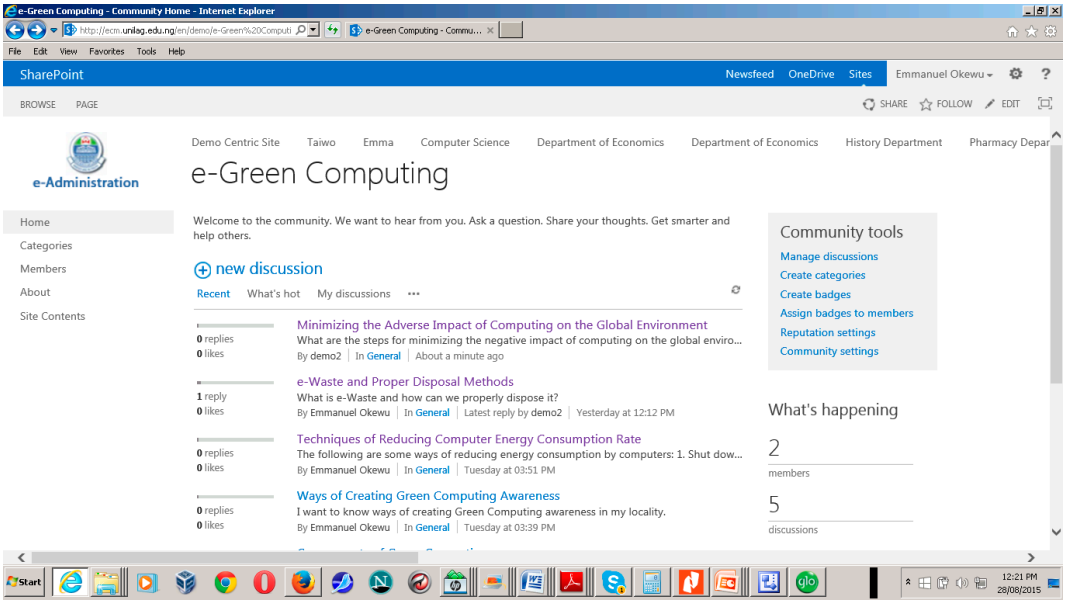

Figure 5. The e-Green Computing site showing community discussion forum for computer users on environmentally friendly computing techniques.

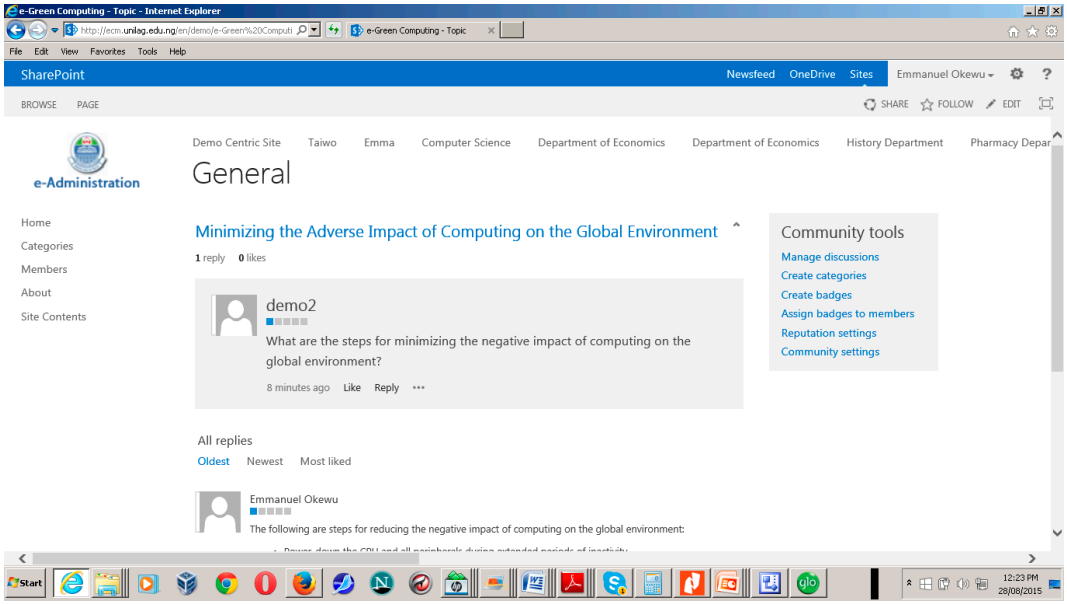

Figure 6. Sample posting by a user seeking to know ways of minimizing the negative impact of computer usage on the environment.

4.2. Results of End-Users Survey

We substantiated our assertion that there is a low level of green computing awareness in Africa by providing empirical data from survey conducted in University of Lagos. For the sample survey, we targeted ICT professionals (network administrators, database administrators, programmers, and students of Information Technology) to gauge their level of green computing awareness. Of the total questionnaires administered, we retrieved 20. A sample size of 50 was used though only 20 responses were received and subsequently used for analysis. Their responses are tabulated in Table 4.

Table 4. Sample Survey Responses.

SN	Statement	Response			
		Yes	**No**	**Abstained**	**Total**
1.	Familiar with Green Computing?	3 (15%)	15 (75%)	2 (10%)	20 (100%)
2.	Green Computing is also referred to as environmentally sustainable computing?	4 (20%)	12 (60%)	4 (20%)	20 (100%)
3.	The aim of Green Computing is to mitigate hazardous material and protect our environment.	7 (35%)	11 (55%)	2 (10%)	20 (100%)

Figure 7 presents graphical view of respondents; responses.

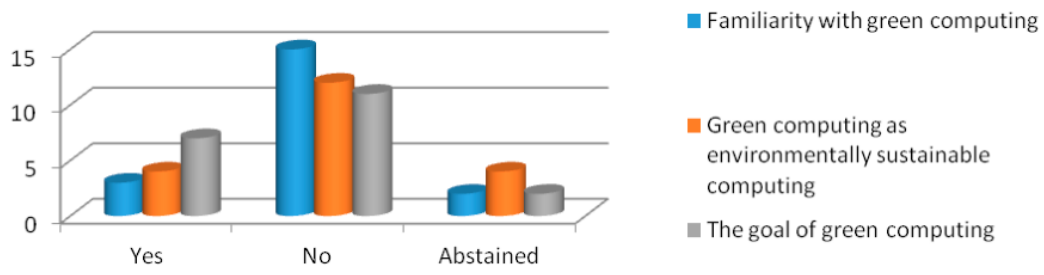

Figure 7. Graphical view of respondents' responses.

From the above respondents' responses, a whopping 75% of the ICT professionals surveyed indicated they had no knowledge of green computing, while a paltry 15% are in the affirmative and 10% refrained from answering. Using this as benchmark to measure the level of green computing awareness among the computer users in the African cyberspace, it is apparent that the continent is lagging behind in environmentally acceptable computing behaviours. Juxtaposing this with the continent's predicted disturbing figures for climate change vulnerability and environmental risk, there is clearly a problem to address as environmental destruction now results in the decimation of livelihoods, economic insecurity and humanitarian crisis. Hence, this attempt to optimize green computing awareness even under uncertainties that are typical of an emerging socioeconomic system like Africa's.

4.3. Evaluation Threats

There is the possibility that an expanded evaluation of the respective components of the e-Green system could unearth fresh perspectives. In any case, the people (Nigerians) that took part in the application test run and sample survey have the required experiential knowledge of the Nigerian cyberspace. They also practiced sufficiently with the e-Green system. Hence, they were in good stead to make objective assessment of the impact of the proposed solution on the green computing awareness campaign. As a result, we took their views seriously [37–40].

Also worthy of mention is the fact that only a select number of computer users where involved in the test run and sample survey, which in some sense has the potential to make the outcome less statistically significant [41,42]. Nonetheless, the sample survey outcome confirmed low-level green computing awareness in the Nigeria computing environment and underscored the need to upgrade efforts in this regard. Likewise, result of the prototype experiment clearly indicates that online real-time sharing of information on moderns steps to green computing could go a long way in achieving environmentally acceptable behaviours. At this juncture in the research project, this is a good result since the main objective is to have an impression of the degree of green computing awareness that can be created by the e-Green Computing system amid uncertainty characterizing the Nigerian socioeconomic terrain. So, in spite the constraint of using few evaluators, it is adequate to conclude that people are favourably disposed to the e-Green Computing system as a tool for promoting environmentally sustainable computing. It means that even in the face of socioeconomic uncertainties, optimizing green computing awareness via online real-time interactions is a reality. We can thus generalize that applying metaheuristic algorithm to the quest for optimal green computing education can enhance environmental sustainability and economic security in Sub-Saharan Africa.

5. Conclusions

The rapid growth of Africa's computing community means a cohesive programme of managing solid e-waste, carbon emission, and conserving energy for other developmental purposes is required. This will ensure that Africa's contribution to global warming and environmental degradation [3] is mitigated. It will also put the continent on the path of sustainable development [7]. Governmental regulation apart, there is need for self-discipline and ecologically friendly disposition to the environment [17] by computer users, and this can be achieved via proper green computing education and awareness campaigns. This study identified various ways national green computing campaigns can be carried out in Africa's socio-cultural context. The researchers considered that despite the emerging nature of African economies and associated stochastic behaviours, optimizing green computing awareness is a possibility though with probable outcomes. We applied metaheuristic algorithm to the stochastic optimization problem to search for the best-known green computing awareness creation solution. Our experiment with Tabu Search indicated that an online real-time dialogue platform will serve the purpose best. Hence, we designed, developed and implemented an e-Green Computing system that proved effective. Component-based software engineering approach was used for reusability of modules across African countries adapting the solution [43].

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